Cancer Incidence in the U.S. Radiologic Technologists Health Study, 1983–1998

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BACKGROUND. Workers exposed to low doses of radiation can provide information regarding cancer risks that are of public concern. However, characterizing risk at low doses requires large populations and ideally should include a large proportion of women, both of which rarely are available.

METHODS. Among 90,305 radiologic technologists in the U.S. (77% women) who were followed during 1983–1998, data concerning incident cancer occurrence was obtained from mailed questionnaires and from death records. Standardized incidence ratios (SIRs) were computed using age-specific, gender-specific, race-specific, and calendar year-specific cancer rates from the Surveillance, Epidemiology, and End Results Program.

RESULTS. The SIR for all cancers in both genders combined was 1.04 (95% confidence interval [95% CI], 1.00–1.07; n = 3292 technologists). Female technologists had an elevated risk for all solid tumors combined (SIR = 1.06; 95% CI, 1.02–1.10; n = 2168 women) and for breast cancers (SIR = 1.16; 95% CI, 1.09–1.23; n = 970 women), melanoma (SIR = 1.66; 95% CI, 1.43–1.89; n = 181 women), and thyroid cancers (SIR = 1.54; 95% CI, 1.24–1.83; n = 107 women). Male technologists experienced a decreased risk for solid tumors (SIR = 0.92; 95% CI, 0.85–0.98; n = 755 men); however, melanoma (SIR = 1.39; 95% CI, 1.00–1.79; n = 56 men) and thyroid cancers (SIR = 2.23; 95% CI, 1.29–3.59; n = 17 men) were increased. Among both genders, the risks were decreased for buccal cavity/pharyngeal cancers (SIR = 0.73; 95% CI, 0.55–0.90; n = 54 technologists), rectal cancers (SIR = 0.62; 95% CI 0.48–0.76; n = 53 technologists), and lung cancers (SIR = 0.77, 95% CI, 0.70–0.85; n = 307 technologists).

CONCLUSIONS. The elevated risk for breast cancer may have been related to occupational radiation exposure. The observed excesses of melanoma and thyroid cancers may reflect, at least in part, earlier detection among medical workers with easy access to health care. ***Cancer*** **2003;97:3080–9.**

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There are approximately 870,000 medical radiation workers who are exposed occupationally to ionizing radiation in the U.S.[1] These workers can provide information regarding cancer risks from low

doses and low-dose rate exposures, which are of greatest interest to the public. Few of the studies of cancer mortality risks among radiologists[2–7] and radiologic technologists[8–12] have included large numbers of women. One exception is the U.S. Radiologic Technologist (USRT) study,[9,11–13] a cohort of 146,022 technologists that includes nearly 107,000 women. A Canadian radiation cohort comprised of 191,000 medical, dental, industrial, and nuclear workers is 50% female, but reported risk estimates from that cohort were aggregated without distinction between medical and nonmedical occupations.[14] Cancer incidence in female medical radiation workers was assessed in 2 other studies, both of which were quite small (5500 women and 3400 women, respectively).[15,16] Although the relation between medical occupational radiation exposure and solid cancers is not clear, increased risks of breast cancer incidence[12] and mortality[9,11,12] were observed in two of four studies that included female radiologic technologists, with the elevated risk generally confined to women who worked in early calendar periods (i.e., before 1950). Similar elevated risks for leukemia have been observed in most epidemiologic cohort studies of radiologists or radiologic technologists, particularly among workers in early periods.[4,7,10,12,15] The USRT cohort study[9,11–13,17] was designed to assess risks related to chronic occupational radiation exposure as well as selected nonradiation factors. In this article, we build upon our earlier mortality analyses and report the methods and results of the first overall assessment of cancer incidence in a nationwide cohort of radiologic technologists.

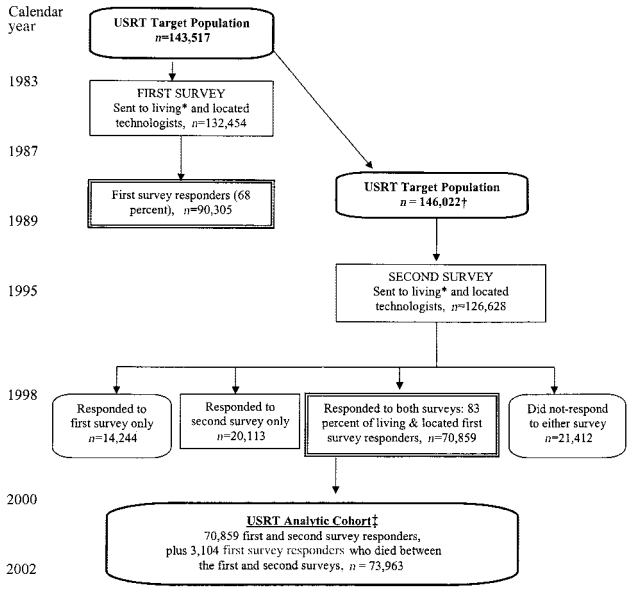

FIGURE 1. Diagram of the target population of U.S. radiologic technologists as of the first and second survey mailings and the resulting analytic cohort for cancer incidence analyses: The U.S. Radiologic Technologist Health Study, 1983–1998 (USRT). Asterisks indicate that, at the time of the first survey, 6350 technologists were deceased; and, at the time of the second survey, an additional 5377 technologists were deceased, including 3104 who completed the first survey. A dagger indicates that the USRT target population included 2505 radiologic technologists who were identified after the first survey. Double daggers indicate that data for the USRT analytic cohort were based on a USRT cohort data freeze (July 01, 2001).

MATERIALS AND METHODS

Study Population

Study methods and cohort descriptions have been published previously.[9,11–13,17] Briefly, a cohort of radiologic technologists was assembled from the computerized certification files of the American Registry of Radiologic Technologists (ARRT) (Fig. 1). Eligibility criteria included certification by the ARRT for $\geq$ 2 years during 1926–1982, and residence in the U.S. or its territories. A mailed questionnaire was sent to 132,454 radiologic technologists who were presumed alive during 1983–1989. Included were questions regarding work history, radiation protection methods, lifestyle characteristics, demographic factors, and health outcomes, including cancer. The analytic cohort included 90,305 technologists who participated in the first survey and who either completed the second survey in the mid-1990s or died between the first and second surveys. This study has been approved annually by the Human Subjects Review Boards of the National Cancer Institute and the University of Minnesota.

Cancer Incidence and Mortality Follow-Up

The USRT cohort has been followed through annual ARRT recertifications, through the tracing of 17,000 inactive registrants using state and national data bases,[9] and through linkage with Social Security mortality files and the National Death Index (NDI) to ascertain vital status. Causes of death were obtained from death certificates or NDI *Plus* and were coded according to the International Classification of Diseases.[18,19] A second mailed questionnaire survey sent in 1993–1998 again assessed cancer and other health outcomes and date(s) of diagnoses of these conditions.

Cancer Validation and Classification

To confirm reported cancers, we obtained medical records from the diagnosing physician or hospital. Reported cancers and the underlying and contributory

TABLE 1
Site-Specific Cancer Validation for Self-Reported Malignancies Occurring between the First and Second Surveys: Positive Predictive Values, Numbers, and Proportions of Incident Cancers Obtained from Death Certificates or from the National Death Index for the U.S. Radiologic Technologist Cohort, 1983–1998

	Incident cancers reported on the second survey and incident cancer deaths							
Disease site	No. of cancers reported	No. of medical records obtained (%)	Cancer reports affirmed among records received[a]	PPV (%)[b]	No. of cancer deaths	Total no. of cancers (self-reports and deaths)	Percentage identified only from death certificates or the NDI	Percentage of death certificates affirmed from Percy et al.[c]
All cancers (excluding NMSC)	2651	1952 (73.6)	1742	89.2	1103	3754	29.4	84.8
Buccal cavity, pharynx	30	16 (53.3)	12	75.0	18	48	37.5	61.5
Esophagus	5	2 (40.0)	1	50.0	14	19	73.7	77.0
Stomach	11	7 (63.6)	5	71.4	29	40	72.5	93.9
Small intestine	1	1 (100.0)	1	100.0	2	3	66.7	79.4
Large intestine (colon)	157	125 (79.6)	95	76.0	84	241	34.9	74.2
Rectum	22	13 (59.1)	11	84.6	16	38	42.1	84.3
Colorectal	179	138 (77.1)	123	89.1	100	279	35.8	95.6
Liver	10	7 (70.0)	0	0.0	21	31	67.7	70.2
Gallbladder	2	1 (50.0)	1	100.0	6	8	75.0	88.9
Pancreas	7	4 (57.1)	2	50.0	56	63	88.9	90.3
Larynx	13	8 (61.5)	8	100.0	2	15	13.3	69.3
Trachea, bronchus, lung, pleura	78	53 (67.9)	46	86.8	237	315	75.2	94.3
Female breast[d]	937	777 (82.9)	772	99.4	216	1153	18.7	98.7
Uterine cervix[d]	198	98 (49.5)	70	71.4	13	211	6.2	93.2
Uterine corpus	134	86 (64.2)	70	81.4	12	146	8.2	93.3
Ovary	63	48 (76.2)	41	85.4	60	123	48.8	91.9
Prostate	192	144 (75.0)	144	100.0	26	218	11.9	98.1
Testis	17	14 (82.4)	11	78.6	1	18	5.5	75.9
Bladder	72	50 (69.4)	50	100.0	8	80	10.0	95.7
Renal, other urinary	52	37 (71.2)	36	97.3	24	76	31.6	93.5
Melanoma[d]	263	171 (65.0)	147	86.0	24	287	8.4	88.6
Brain	24	16 (66.7)	11	68.7	38	62	61.3	93.1
Thyroid	125	104 (83.2)	96	92.3	3	128	2.3	96.6
Bone and joints	24	10 (41.7)	1	10.0	2	26	7.7	65.9
Connective and soft tissue	29	18 (62.1)	8	44.4	9	38	23.7	49.4
Non-Hodgkin lymphoma	70	59 (84.3)	52	88.1	45	115	39.1	92.8
Hodgkin disease	29	21 (72.4)	20	95.2	4	33	12.1	95.6
Multiple myeloma	17	10 (58.8)	6	60.0	16	33	48.5	97.2
Lymphoid leukemia	20	16 (80.0)	13	81.2	17	37	45.9	80.6
Myeloid leukemia	7	6 (85.7)	6	100.0	16	23	69.6	86.0

PPV: positive predictive value; NDI: National Death Index; NMSC: nonmelanoma skin cancer.

[a] Pathology reports, discharge summaries, operative reports, clinical records, physician questionnaires, and physician letters were used to confirm the reported cancers.

[b] The positive predictive value was calculated as follows: [the number of self-reported cancers affirmed (same cancer that was reported)/number of records obtained] × 100.

[c] The % confirmation rate, as reported in Percy et al.[21]

[d] Uterine cervix cancer, breast cancer, and melanoma reports include both in situ and invasive cancers.

causes of cancer deaths from death records were coded according to the International Classification of Diseases for Oncology.[20] Based on Percy et al.[21] (shown in the last column of Table 1) we believed that the misclassification of cancer deaths probably would be low and, thus, did not independently verify death certificate diagnoses except to ascertain leukemia subtypes.

Statistical Analysis

We computed standardized incidence ratios (SIRs) using age-specific, gender-specific, race-specific, and calendar year-specific cancer incidence rates from nine United States population-based registries of the Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute.[22] To calculate the expected number of cancers, we applied the

SEER cancer incidence rates to the age (in 5-year age groups), gender, race, and 5-year calendar-period person-time distribution of the cohort. Follow-up time for each technologist began on the date of completion of the first survey and continued until the date of completion of the second survey or the date of death (through August 1998), which ever occurred first.

Of the 90,305 individuals who responded to the first survey, we could not determine cancer incidence during the follow-up period for 16,342 individuals (2098 individuals could not be located, and 14,244 individuals did not respond to the second questionnaire). We accounted for the missing information by using response propensity models to weight the respondents.[23,24] Logistic regression was used to model the propensity to respond to the second survey separately for male and female technologists, conditional on covariates from the first questionnaire and selected ARRT certification information. The covariates that were predictive of nonresponse for men were region of residence, race, number of years certified as a radiologic technologist, marital status, smoking status, year first worked, and an interaction term of year first worked and marital status. For women, in addition to the above-described covariates, we included oral contraceptive (OC) use (ever/never) and interaction terms of the number of years certified and marital status; the number of years certified and OC use; the year first worked and region of residence in the U.S.; and the race and region of residence in the U.S. The weights applied to individual responses were the inverse of this response probability and essentially restored the baseline sample of 90,305 technologists. Individuals who died between the first and second surveys were considered to have complete responses and were assigned weights equal to 1.

We used Jackknife methods to estimate the variance of the SIRs.[24] For the cancer sites with ≥ 50 observed incident cases, the normal approximation was used to compute confidence limits; whereas, for cancer sites with < 50 observed incident cases, we adjusted the confidence limits using the Poisson distribution.[24] If the observed number of incident cases was zero, then we computed the confidence limits using the exact test described by Liddell.[25]

Because multiple primary cancers are included in the calculation of the SEER referent cancer rates, we followed individuals who reported a prevalent cancer in the first survey as well as cancer free individuals for multiple primary cancers. Similar to the method used by the SEER Program, we allowed only one diagnosis if two or more of the same conditions were self-reported or were found on death records for multiple myeloma, non-Hodgkin lymphoma, Hodgkin disease, and the leukemias.

To assess the accuracy of the technologist's personal report of a cancer diagnosis, we compared self-reports with information obtained from medical and pathology records to calculate the positive predictive value (PPV), which was defined as PPV $= a/b \times 100$, in which a is the number of reported site-specific cancers confirmed from medical records, and b is the number of reported site-specific cancers for which medical records were available. For cancers of liver, bone, and brain, individuals may not distinguish primary cancers from metastatic cancers to these sites. Therefore, for cancer sites with a high metastatic potential (cancers of the liver, bone or joints, soft tissue, and brain) and for uterine cervical cancer (due to large numbers [48 of 98 women] diagnosed with carcinoma in situ), we included in the SIR calculations only self-reported cancers that were validated with medical records. Therefore, the cancers analyzed included reported and confirmed invasive cancers (in situ cancers excluded), reported cancers for which pathology reports or medical records could not be obtained, and reported cancers for which medical records confirmed another anatomic site (for example, a reported colon cancer that was confirmed as a cancer of the rectum and was classified in our final data set as a cancer of the rectum). However, reported cancers without a date of diagnosis were not included in the analysis ($n = 331$ cancers). For these reasons, the cancer numbers described in Table 1 cannot be used easily to derive the numbers of cancers in subsequent tables.

RESULTS

The total number of incident cancers identified in the second survey was 2651, for which 73.6% of medical records were obtained (Table 1). The overall proportion of self-reports confirmed (PPV) was 89.2%, but proportions varied substantially according to cancer site. For cancer sites with ≥ 100 reported incidents, PPVs ranged from 71.4% for uterine cervix cancer to 100% for prostate cancer. The PPV for breast cancer (the site most frequently reported) was 99.4%. PPVs for thyroid cancer, lung cancer, and all leukemias were 92.3%, 86.8%, and 86.4%, respectively. Another 1103 incident cancers (29.4%) were identified from death certificates or the NDI. Cancer site-specific results from a death record validity study[18] are presented in Table 1 (last column) and show confirmatory percentages $> 90\%$ for cancer sites for which we relied on death certificates for $> 75\%$ of the incident cancers.

The USRT cohort was predominantly white (94.8%), female (77.0%), and young (the median age of the cohort at the time of completion of the first survey

TABLE 2
Descriptive Characteristics of the Study Cohort that Responded to the First Survey (1983–1987) and the Number of Incident Cancers that Occurred in Each Subgroup by the Time of the Second Survey (1994–1998): The U.S. Radiologic Technologist Cohort, 1983–1998

	Females		Males		Total	
Characteristic	No. of individuals	No. of cancers	No. of individuals	No. of cancers	No. of individuals	No. of cancers
Ethnicity						
White	66,827	2324	18,794	821	85,621	3145
Black	1599	45	798	31	2397	76
Hispanic	446	7	496	14	942	21
Asian	431	14	507	12	938	26
Other	221	18	186	6	407	24
Age at first survey (yrs)						
<29	14,216	183	2216	14	16,432	197
30–34	18,061	286	4776	52	22,837	338
35–39	13,906	356	4545	65	18,451	421
40–44	9061	380	2941	70	12,002	450
45–49	5692	339	1959	101	7651	440
≥50	8588	864	4344	582	12,932	1446
No. of yrs worked at the time of the first survey[a]						
1–9	34,475	916	7680	186	42,155	1102
10–19	26,201	871	7816	233	34,017	1104
20–29	5638	402	2928	212	8566	614
≥30	1468	159	1610	222	3078	381
Age began working (yrs)[a]						
<18	1487	66	255	18	1742	84
18–19	30,631	930	4600	142	35,231	1072
20–21	21,410	636	5033	139	26,443	775
22–24	8032	294	5192	200	13,225	494
≥25	6222	422	4954	354	11,176	776
Decade began working[a]						
Before 1950	3561	442	1707	295	5268	737
1950–1959	9143	638	2953	265	12,096	903
1960–1969	21,392	712	5407	164	26,799	876
1970 or later	33,686	556	9967	129	43,653	685
Total	69,524	2408	20,781	884	90,305	3292

[a] Values may not sum to the total, because some technologists who were certified by the American Registry of Radiologic Technologists never worked or their work history data are missing, (n = 2489 individuals and 91 incident cancers).

was 36 years). Half of the cohort had worked for 10 years or more at the time of the first survey, and 40.9% of the cohort began working as radiologic technologists before age 20 years. The majority of the cohort (78.0%) first worked as radiologic technologists in 1960 or later (Table 2).

For all radiologic technologists, overall cancer incidence was elevated marginally (SIR = 1.04; 95% confidence interval [95% CI], 1.00–1.07) compared with the general U.S. population in the geographic regions included in the SEER Program. The increase, however, was confined to female technologists (Table 3). Male technologists experienced a slight deficit in overall cancer risk compared with the general U.S. population (SIR = 0.94; 95%CI, 0.89–1.00). For women, excesses were observed for all solid tumors combined and specifically for breast cancer, melanoma, and thyroid cancer. For men, excesses were seen for melanoma and thyroid cancer. The risk for total leukemia was increased modestly in female technologists, but results for leukemia subtypes were inconsistent by gender, with no clear pattern. Risks for multiple myeloma were decreased slightly and similarly in both genders, whereas risks for Hodgkin disease were higher than expected in both genders. For non-Hodgkin lymphoma, the risk was elevated slightly in women but was close to expectation in men. Women had lower risks than expected for cancers of the rectum, uterine cervix, and lung. Men experienced decreased risks for cancers of the buccal cavity or pharynx and lung.

DISCUSSION

Radiologic technologists had increased risks of female breast cancer, thyroid cancer, and melanoma but had

TABLE 3
Cancer Site-Specific Standardized Incidence Ratios Weighted for Nonresponse in Females and Males and in Both Genders: The U.S. Radiologic Technologist Cohort, 1983–1998

	Females (n = 69,524; 595,714 person yrs[a])			Males (n = 20,781; 163,749 person yrs[a])			Males and females (n = 90,305; 759,464 person yrs[a])		
Disease site	No. of cancers observed	SIR	95% CI	No. of cancers observed	SIR	95% CI	No. of cancers observed	SIR	95% CI
All cancers (excluding NMSC)[b]	2408	1.07	1.03–1.11	884	0.94	0.89–1.00	3292	1.04	1.00–1.07
All solid tumors	2168	1.06	1.02–1.10	755	0.92	0.85–0.98	2923	1.02	0.98–1.05
All hematolymphoproliferative	173	1.16	0.96–1.36	95	1.07	0.88–1.27	268	1.13	0.97–1.28
Buccal cavity, pharynx	35	0.94	0.64–1.32	19	0.52	0.31–0.83	54	0.73	0.55–0.90
Esophagus	9	1.18	0.51–2.33	13	0.93	0.46–1.68	22	1.02	0.59–1.63
Stomach	19	0.87	0.50–1.41	17	0.82	0.46–1.37	36	0.85	0.58–1.20
Small intestine	4	0.66	0.16–1.75	0	0.0	0.0–0.96	4	0.42	0.10–1.12
Large intestine (colon)	133	1.04	0.90–1.17	77	1.10	0.86–1.34	210	1.06	0.94–1.17
Rectum	29	0.56	0.37–0.82	24	0.71	0.44–1.07	53	0.62	0.48–0.76
Liver	10	1.44	0.56–3.03	4	0.40	0.09–1.15	14	0.83	0.42–1.47
Gallbladder	4	0.65	0.15–1.78	1	0.80	0.01–5.31	5	0.67	0.18–1.72
Pancreas	38	1.06	0.73–1.49	21	0.96	0.56–1.54	59	1.02	0.76–1.29
Larynx	7	0.74	0.28–1.57	10	0.59	0.27–1.12	17	0.64	0.36–1.05
Lung and bronchus	177	0.77	0.68–0.87	130	0.77	0.64–0.89	307	0.77	0.70–0.85
Breast	970	1.16	1.09–1.23	2	1.13	0.12–4.23	972	1.16	1.09–1.23
Uterus, including cervix	177	0.80	0.69–0.90	—	—	—	177	0.80	0.69–0.90
Ovary	99	0.88	0.71–1.05	—	—	—	99	0.88	0.71–1.05
Prostate	—	—	—	222	1.02	0.89–1.16	222	1.02	0.89–1.16
Testis	—	—	—	16	1.32	0.76–2.13	16	1.32	0.76–2.13
Bladder	33	0.93	0.64–1.32	50	0.93	0.65–1.30	83	0.93	0.70–1.17
Kidney	38	1.19	0.78–1.75	29	1.16	0.73–1.75	67	1.18	0.84–1.52
Melanoma	181	1.66	1.43–1.89	56	1.39	1.00–1.79	237	1.59	1.38–1.80
Brain	33	0.91	0.61–1.31	20	1.04	0.59–1.70	53	0.95	0.75–1.16
Thyroid	107	1.54	1.24–1.83	17	2.23	1.29–3.59	124	1.61	1.34–1.88
Bones and joints	3	0.86	0.18–2.48	3	1.71	0.28–5.47	6	1.11	0.39–2.48
Soft tissue	15	1.26	0.69–2.11	4	0.69	0.16–1.88	19	1.08	0.64–1.71
Non-Hodgkin lymphoma	88	1.21	0.95–1.48	47	1.03	0.74–1.40	135	1.14	0.95–1.34
Hodgkin disease	21	1.28	0.79–1.96	11	1.69	0.83–3.06	32	1.40	0.96–1.98
Multiple myeloma	16	0.90	0.49–1.52	10	0.89	0.39–1.73	26	0.90	0.57–1.36
All leukemia	48	1.12	0.81–1.51	27	1.04	0.66–1.56	75	1.09	0.87–1.32
ALL	2	0.61	0.05–2.47	3	2.20	0.41–6.73	5	1.13	0.34–2.76
CLL	14	1.25	0.58–2.35	10	1.10	0.50–2.09	24	1.18	0.72–1.83
ANLL	22	1.25	0.76–1.93	7	0.83	0.30–1.80	29	1.11	0.72–1.63
CML	8	1.03	0.41–2.13	3	0.64	0.10–2.13	11	0.89	0.41–1.67
Other and ill defined sites[c]	67	1.63	1.28–1.99	34	1.46	0.95–2.14	101	1.57	1.25–1.89

SIR: standardized incidence ratio; 95% CI: 95% confidence interval; NMSC: nonmelanoma skin cancer; ALL: acute lymphocytic leukemia; CLL: chronic lymphocytic leukemia; ANLL: acute nonlymphocytic leukemia; CML: chronic myeloid leukemia.

[a] Weighted number of persons and person years

[b] Nonmelanoma skin cancer was not included, because this cancer is not collected by the Surveillance, Epidemiology, and End Results (SEER) Program.

[c] Other and ill-defined sites include unknown primary site (total = 96: 64 among females, 32 among males), other and ill-defined abdominal sites, not otherwise specified (total = 2 among females), other ill-defined sites (total = 2 among males), and Waldenstrom macroglobulinemia (total = 1 female).

no consistent increased risk for any of the leukemia histologic subtypes. The modestly elevated breast cancer risk noted in the current study was consistent with results among 5443 female medical radiation workers in China. Incident breast cancer rates were elevated (relative risk [RR] = 1.34; based on 46 patients) compared with the incidence among 8088 female physicians who did not use X-rays routinely.[15] A study of 4151 Danish radiotherapy staff (82% female)[16] found no dose-response association between breast cancer risk and radiation badge dose, but the overall breast cancer point estimate (SIR = 1.29; 95% CI, 0.87–1.73; n = 44 individuals) was similar to our finding. Among the 95,690 female Canadian radiation workers, breast cancer risk was slightly lower than expected (SIR = 0.93; 95% CI, 0.93–1.00; n = 544 individuals), but the

average cumulative radiation dose among women was extremely low (1.8 mSv).[14] The most recent breast cancer mortality analysis conducted within the USRT cohort found an increased risk for radiologic technologists first employed prior to 1940 that decreased in later decades.[11,12]

The increased risk of thyroid cancer in the USRT cohort is consistent with the elevated risk among Chinese medical X-ray workers (RR = 1.58; n = 14 individuals)[15] and among 191,000 Canadian radiation workers, 57% of whom were employed in dental or medical jobs (SIR = 1.39; 95% CI, 1.20–1.61; n = 129 individuals).[14] Because 40% of the USRT cohort began working as radiologic technologists before age 20 years (an age when acute radiation exposure showed increased risk of thyroid cancer among atom bomb survivors),[26] we evaluated thyroid cancer SIRs according to the age at which the technologist first was employed, but we found no association with age first worked (data not shown). The excess risk of melanoma was somewhat unexpected, because there is little support for an association with ionizing radiation exposure, but the data are sparse.[1] Although an elevated risk was observed among atom bomb survivors, malignant melanoma is rare in Japanese populations, and risk was based on few cases.[27] The SIR for melanoma was increased modestly among the Canadian radiation workers based on 222 incident cases in both genders (SIR = 1.16; 95% CI, 1.04–1.30) but was curiously limited to dental workers, who had the lowest radiation doses.[14] Internal USRT cohort analyses of incident melanoma, adjusted for multiple risk factors, revealed increased melanoma risks associated with beginning to work prior to 1950 but were based on small numbers.[13] The role of chronic low-dose to moderate-dose radiation exposure and melanoma risk probably will require additional study to resolve the nature of the association.

Another partial explanation for the elevated breast cancer, thyroid cancer, and melanoma SIR estimates in the USRT cohort is heightened awareness and access to early detection among medical radiation workers. We believed that the availability (most active workers would be insured by hospital health plans) and use of screening technologies would be a more direct indicator of the effect generally ascribed to higher socioeconomic status when occupational cohorts are compared with general population cancer registries. Thus, to investigate screening mammography use in the USRT cohort, we compared the proportion of women age $\geq$ 40 years who reported ever having had a mammogram with the proportion who reported ever having had a mammogram from the Behavioral Risk Factor Surveillance System (BRFSS).[28,29] We found that women in the USRT cohort were slightly more likely ever to have had a mammogram (47.2% and 87.0% from the first and second questionnaires, respectively) compared with women in the U.S. who responded to the BRFSS survey (44.1% and 83.4% in 1987 and 1995, respectively). However, this small difference would not account for much of the elevated breast cancer SIR in the USRT cohort.

With regard to thyroid cancer and melanoma, there are no easy means to evaluate screening practices; however, it is known that thyroid cancer incidence is higher in closely monitored populations compared with background incidence rates.[30] To assess indirectly the potential for increased screening, we reviewed available copies of the medical and pathology reports for thyroid cancer (n = 93 individuals) and melanoma (n = 103 individuals) that were obtained for our cancer incidence validation to determine whether tumor or lesion size was smaller among the radiologic technologists compared with the size of tumors or lesion reported to the SEER tumor registries. We used the SEER data base and public domain software SEER Stat[22] to obtain frequencies of localized diagnoses of thyroid tumors and melanomas. We found that radiologic technologists tended to have smaller thyroid tumors and melanomas at the time of diagnosis, as determined by tumor size in centimeters for thyroid cancer and by lesion thickness (Breslow depth) for melanoma. For example, small thyroid tumors (0.5–1.0 cm) were found in 30% of radiologic technologists, compared with 15% in the SEER data base; and larger tumors (1.5–2.5 cm) occurred in 19% of radiologic technologists compared with 28% in the SEER data base. Melanomas with a depth $<$ 0.75 mm were found for 78% of radiologic technologists who had localized melanoma compared with 60% in the SEER data base. Another consideration is that the number of melanomas that are not reported to registries has been increasing,[31] and at least one study indicated that the underreports often are thin melanoma lesions.[32] If this is true, then the underreporting to registries would lower expected values, resulting in inflated SIRs in this and other cohort studies of malignant melanoma.

Modest but nonsignificant increased risks were seen for both radiogenic (acute nonlymphocytic among women) and nonradiogenic (chronic lymphocytic, primarily among women) forms of leukemia, based on small numbers. Leukemia risks among medical radiation workers are elevated fairly consistently for exposures that occurred many decades ago.[4,7,10,12,15] Given the relatively short induction period of radiogenic leukemias compared with solid can-

cers, the null results may reflect the relatively low radiation exposures in more recent periods.[33]

Cancer sites with fewer cases than expected included lung, buccal cavity, uterine cervix, and rectum. Lung cancer, although considered a radiogenic site, has occurred less frequently than expected in several occupational radiation cohorts, particularly for comparisons made with external populations.[14,34] The decreased risk of lung cancer and, perhaps, other smoking-related cancers may reflect a lower prevalence of current smoking in the USRT cohort at the time of the first survey questionnaire (females, 23%; males, 25%) compared with the U.S. population (females, 29%; males, 31%).[35] Thus, a portion of the reduced risks observed for cancers of the buccal cavity, larynx, and possibly the bladder may reflect the lower smoking prevalence in the USRT cohort. The significant deficit observed for cancers of the uterine cervix reflects our conservative approach of excluding unconfirmed reports of cervical cancer. The deficit in cancer of the rectum is consistent with most reports of reduced or no elevation of rectal cancer risk in other radiation-exposed cohorts.[6,10,26,36]

The USRT cohort study has several strengths, including the large nationwide distribution, virtually complete vital status ascertainment, and large proportion of women. Unique to our cancer incidence analysis was adjustment for missing responders among technologists who were lost to follow-up or did not participate in the second survey. We found multiple predictors of nonresponse in our cohort, suggesting that selection bias may be a concern, and we incorporated this information into our analyses. Although adjusting for missing responders did not alter the site-specific SIRs or the precision appreciably in this particular application, the SIRs reported here generally were adjusted slightly downward compared with SIRs that were unadjusted for nonresponse. The weighting procedure we used is employed frequently in survey methodology[23,24] but is used rarely in epidemiologic cohort analyses. Investigators may wish to consider wider incorporation of such methods when questionnaire administration is infrequent, when baseline information from an initial survey or other sources is plentiful and indicates differences in characteristics among responders versus nonresponders, and when there are substantial numbers of nonrespondents.

The accuracy of self-reported cancers in the current study (overall PPV = 89%) is similar to what has been reported in other studies (range, 75–100%).[37–41] We were able to obtain medical records, pathology reports, or physician's notes for nearly 74% of the cancers reported by the technologists in the second cohort survey. The 74% of records obtained in the current study is similar to other cohort studies that used similar approaches to cancer validation, in which medical records were obtained for 68–90% of self-reported cancers.[37,40–42] Although we verified a satisfactory proportion of self-reported cancer diagnoses, underreporting of cancer diagnoses is also a concern, with false negative cancer self-reports ranging from 17% to 44%.[38,43] We were unable to assess the extent of cancer underreporting in the current analysis among the radiologic technologists because of the past infeasibility of linking a nationwide cohort to cancer registries with sufficient coverage; however, the effect of correcting for underreporting would be to increase the risk estimates.

Despite the current study's strengths, a number of limitations remain. Although we tried to account for over 16,000 missing respondents, it is possible that cancer rates in nonresponders differed from those who responded, and the effect on the SIR estimates may be increased or decreased. The healthy worker effect may be responsible for the lower SIRs observed for lung cancer, buccal cavity cancer, and rectal cancer; whereas the increased SIRs observed for melanoma and thyroid cancer may be at least partially explained by easy access to health care (and the likelihood of health insurance) of radiologic technologists compared with the SEER population. Although they were beyond the scope of the current analysis, several cancer site-specific USRT cohort analyses are underway with the objective of describing occupational radiation exposure more fully in relation to incident breast cancer and thyroid cancer.

The USRT cohort is a large, nationwide, predominantly female working population exposed to chronic, low- to moderate-dose radiation. Cancer validation efforts in the cohort have demonstrated good agreement between self-reported and medical record-confirmed cancer diagnoses. We found elevated risks for breast cancer, melanoma, and thyroid cancer that also were seen in other radiation worker cohorts. The breast cancer excess is consistent with a radiation etiology, in that the risk is highest among technologists who were first employed before 1940,[12] when exposures were greatest. It is less clear from this analysis whether the melanoma and thyroid cancer excesses are radiation-related or reflect, at least in part, increased awareness and diagnostic vigilance in a population with easy access to health care. Because of the relatively young mean age of the USRT cohort (approximately 53 years), continued surveillance of radiologic technologists will be important as the population enters the ages with increasing spontaneous cancer occurrence.

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